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Energy Transition and European Sub-Models. Restructuring EU Economy

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Abstract. *The European Union (EU) stands at the forefront of the global energy transition, committed to transforming its economy by adopting sustainable energy sources. This paper explores the diverse European sub-models of energy transition, highlighting different patterns among the EU Member States within the context of their particularities. Using the hierarchical cluster methodology and the panel data model with fixed effects for the period 2010-2021, we analyze the broader implications of the energy transition for the restructuring of the EU economy, with a focus on key sectors such as power generation, manufacturing, and social aspects. The study identifies significant challenges, including the need for substantial investment and technological innovation, as well as economic competitiveness, and social consequences. Additionally, the paper illustrates the complex interplay between climate objectives and economic restructuring within the EU, offering insights into the potential of the energy transition to not only mitigate climate change but also to drive socio-economic development and resilience.*

Keywords: Energy transition, economic models, renewable energy, social models, investment, economic growth

Introduction

The dawn of the 21st century has marked a pivotal shift in the global energy paradigm, characterized by a concerted move away from fossil fuels toward more sustainable and renewable energy sources. This global energy transition, driven by the urgent need to address climate change and reduce greenhouse gas (GHG) emissions, has emerged as a central issue for economies worldwide.

The European Union (EU) aims to reduce its GHG emissions by 55% until 2030 compared to 1990 levels and become climate neutral by 2050, the renewable energy being the core pillar of its clean energy transition as part of its broader strategy for sustainable development (see for example the Green Deal[1] agreement and Paleari, 2022). The EU's approach to the energy transition is characterized by a plethora of measures given its varied sub-models, reflecting the diverse cultural, economic, geographic, and political particularities of its member states. These varied approaches underscore the complexity of implementing a comprehensive energy transition that balances economic growth with environmental sustainability. For instance, with the intensive use of wind farms in the Nordic countries, and the solar energy in Spain and Italy, the European countries are adopting a variety of strategies to integrate renewable energy sources into their economies and to eliminate the use of fossil fuels based on their current power energy mix and potential for renewable sources (Pickering et al., 2022).

[1] European Commission, *The European Green Deal - Striving to be the first climate-neutral continent* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

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The implications of the energy transition and development of new clean technologies extend far beyond environmental benefits, heralding significant economic restructuring across the EU. Following fossil fuels phase out objectives and accelerated renewable energy deployment, new industries emerge, presenting both challenges and opportunities for the European economy.

This paper aims to explore such dynamics, presenting an analysis of how the energy transition is reshaping economic landscapes across the EU. Also, the paper contributes to the existing literature focusing on EU model's reshaping and its socio-economic sub-models (Aiginger, 2008; Esping Andersen, 1990), embedding the new path assumed by the EU, respectively the macroeconomic effects of the energy transition.

Using a hierarchical cluster analysis and panel data with fixed effects quantitative model, our study provides insights into the economic, technological, and policy-driven aspects of this complex process. The first part of the research covers the literature review relevant to our inquiry related to energy transition and its relationship with economic growth. The second part presents the methodological approach, the variables and research hypotheses respectively, while the third part reflects the results of the proposed models. The paper ends with conclusions and further research suggestions.

Literature review

The pillars of the energy transition in the (EU) are fundamentally aimed at sustainability, security of energy supply, and economic competitiveness, with a strong emphasis on decarbonisation, energy efficiency, and the development of renewable energy sources (Buschle and Westphal, 2019). However, several studies (see Rabbi et al. (2022), Papadis and Tsatsaronis, 2020) show that the path toward achieving these goals is fraught with bottlenecks and structural deficiencies. One notable bottleneck is the integration of renewable energy sources into the existing energy grid, which requires significant investment in grid infrastructure to manage the variability of renewable energy. Additionally, regulatory frameworks and market designs often lag technological advancements, inhibiting the seamless incorporation of new energy solutions into the market. Hernandez Serrano and Zaveri (2020) underscore the critical role of household net income and government policies in driving the energy transition, suggesting a need for supportive policies and financial mechanisms to overcome these challenges.

These mechanisms could be essential especially for different types of consumers, like vulnerable consumers or large strategic consumers, from heavy industry, metallurgy, cement, or agricultural fertilizers. Also, Hernandez-Serrano and Zaveri (2020) highlight the role of household income and government policies in facilitating the economic shift. The energy transition's complexity is further underscored by economic and structural differences across European regions, such as the Nordic countries, which have significantly invested in wind and hydroelectric power, contrasting with Central and Eastern European members that depend more heavily on coal and other fossil fuels, like Romania, Poland or Bulgaria (Ćetković and Buzogány, 2019; Alves Dias et al, 2018; Davies et al., 2020). Moreover, the high diversity in energy mix and GHG emissions among EU member states reflect high regional disparities. For instance, the Nordic model, with its heavy reliance on renewable energy, sets a benchmark in low carbon emissions and energy sustainability.

In contrast, Southern European countries, with a more favorable climate for solar energy, are yet to fully capitalize on this potential. The research by Alaton et al. (2020) on Energy Communities in the EU highlights the legislative framework introduced in 2019 to foster renewable and energy communities, demonstrating a policy-driven approach to encourage diverse and localized energy solutions across the union. The economic structural differences among EU regions play a critical role in their energy transition capabilities (Voicu-Dorobanțu et al., 2021). Countries in Central and Eastern Europe face significant challenges due to their historical dependence on heavy industries and coal-based energy production, which are major sources of CO2 emissions. Also, there is the Continental model, where countries exhibit a more balanced energy mix and are further along in integrating renewables into their grid.

The wavelet cohesion approach to business cycle synchronization within the EU, as studied by Hanus and Vacha (2015), provides insights into how economic factors and EU membership influence the synchronization and, indirectly, the capacity for energy transition across different regions. These differences underscore the need for tailored policies that consider each region's unique economic structure, energy mix, and environmental impact to effectively navigate the energy transition in the EU.

Another important aspect of the energy transition is the impact on prices, competitiveness, energy poverty, and economic disparities among regions within the EU. The literature shows that the transition to renewable energy sources and the implementation of energy efficiency measures can lead to long-term reductions in energy costs and enhance economic competitiveness (Gielen et al., 2019). However,, the upfront costs can intensify energy poverty and widen economic disparities, especially in regions that are heavily reliant on traditional energy industries or have less capacity to invest in new technologies. Jianu et al. (2020) delve into the implications of institutional particularities on income inequalities within the EU, highlighting the importance of considering institutional frameworks when assessing the impact of energy policies on economic disparities.

To address these concerns, the literature highlights socio-economic considerations, policy innovation, and cross-sectoral collaboration in energy transition. The literature suggests that a successful energy transition requires a concerted effort that involves three pillars: government support, private sector investment, and community engagement (see Gielen et al., 2019; McCauley and Heffron, 2018). Additionally, policies should be tailored to the specific needs and capabilities of different regions to ensure an equitable transition that minimizes negative social and economic impacts while maximizing the benefits of a cleaner, more sustainable energy system (Markkanen and Anger-Kraavi, 2019; Vona, 2019; Valer et al., 2014). Using a panel data analysis, Apostu et al. (2023) associate green environment, economic growth, and circular economy within the European countries. Their results show that gross fixed capital formation and total GHG emissions lead to a decreasing generation of municipal waste in 2009-2021; instead, final energy consumption, GDP, SOx emissions, and NOx emissions generate an increase in the generation of municipal waste. Moreover, efficient resource utilization diminishes production expenses, thereby potentially swelling GDP per capita (Sverko et al., 2020).

Mohammed et al. (2024), construct an empirical environmental Kuznets curve (EKC) to assess the impact of CO2 emissions, energy consumption (EC), population structure (POP), economy (GDP), and policies on the environment within the EU. Their model shows that EU Member States have an inverted-U-shaped relationship between GDP and CO2 emissions, respectively that a 1% increase in GDP results in a 0.7 p.p. increase in carbon emission, while a 1% increase in GDP leads to a 0.06 p.p. reduction in CO2 emissions in the long run. This indicates that economic development within the EU has reached a stage where economic growth might positively impact the environment. These effects are anchored in significant structural changes within the economy, an increased reliance on renewable energy sources, a transition towards less carbon-intensive fuels, and substantial improvements in energy efficiency (see also Simionescu et al., 2022).

Economic transformation involves shifting from industries and practices that are heavily dependent on fossil fuels towards sectors that are more sustainable and less carbon-intensive, like the growth of the service sector, digital economy, and industries that prioritize circular economy principles, such as recycling and resource efficiency (Wang et al., 2023; Le and Ozturk, 2020).

The public sector's governance quality is a critical component in this process. It can streamline and potentiate the enactment of environmental tax policies, incentivizing a downtrend in per capita emissions and bolstering the circular economy. Aydin et al. (2024) findings suggest that in their efforts to obtain a sustainable environment, policymakers should invest in the research and development sector for better environmental technologies, increase the standards of institutions in the future, also to take globalization issues into account, like trade and its effect in emerging countries with lower environmental regulations.

The public sector's capability to adapt can significantly influence social and economic outcomes, especially in the current landscape, with high inflation and lower economic growth rates in Europe, which will likely result in weaker government revenues and a narrowed fiscal capacity for governments.

In our view, the EU context provides a rich backdrop for analyzing the interplay between variables related to environment, social factors, public sector governance, energy transition, and the overall economy (see the cluster analysis from the following sections) that creates a multi-layered landscape among European regions and countries that will be identified in the next sections.

Methodology

From a methodological perspective, we used two types of analysis in this paper. First, we developed a cluster analysis to highlight different regional patterns based on common characteristics among the EU member states (see Table 1 below). The research hypotheses of the study are substantiated based on the current socio-economic-energy models among the analyzed countries and the role of renewable energy investment in decarbonization efforts, as follows:

Hypothesis 1: Cluster-Specific Energy Transition Patterns and Economic Performance – The energy transition patterns are significantly associated with differences in economic performance among EU Member States.

Hypothesis 2: Impact of renewable energy investment – Increased investment in renewable energy sources significantly reduces per capita emissions in EU Member States, highlighting the effectiveness of transitioning to sustainable energy solutions in achieving decarbonization goals.

To identify more regional economic (sub-)models within the EU, we used a hierarchical cluster analysis model. Hierarchical cluster analysis is a grouping algorithm used in data analysis and involves grouping categories of similar objects, entities, or data points to form clusters based on their degree of similarity or dissimilarity. The software program used was SPSS 26. The developed model is a hierarchical cluster analysis of the agglomerative type (based on finding similar, close characteristics among the groups of EU states) and was based on several structural socio-economic and environmental/energy indicators from the period 2010-2021.

Table 1. Categories of indicators used for the cluster analysis

Natural Environment	Social	Public Sector
Resource Productivity (Source: Eurostat)	Population at risk of poverty (Source: Eurostat)	Environmental tax revenue as a percentage of GDP (Source: Eurostat)
Per capita emissions (Source: Eurostat)	Unemployment rate 20-64 years (Source: Eurostat)	Public spending as a percentage of GDP (Source: Eurostat)
Circularity rate (Source: Eurostat)	Gini Index (Source: Eurostat)	Government quality (Source: World Bank)
Investments in circular economy (Source: Eurostat)	Social protection expenditure per capita (Source: Eurostat)	
	Arrears in household payments – utilities (Source: Eurostat)	

Energy	Economy
Share of renewable energy resources (Source: Eurostat)	GDP per capita (Source: Eurostat)
Share of fossil fuels (Source: Eurostat)	Investment in GDP (Source: Eurostat)
Energy dependency (Source: Eurostat)	Industry's share in GDP (Source: Eurostat)

Source: Authors' work.

The data was collected from various sources (as presented in Table 1). Based on the Euclidean distance and the mean link method, we defined the clusters and the distance between them using the SPSS 26 software program. The Euclidean distance between two observations or variables is the square root of the sum of the square differences between their values for all variables (as presented in the formula below):

$$d\,(p,q) = \sqrt{\sum_{i=0}^{n} (qi - pi)^2}$$

where *p*, *q* = two points in Euclidean n space; *qi*, *pi* = Euclidean vectors, starting from the initial point; *n* = *n-space.*

Subsequently, based on the hierarchical analysis of clusters, we obtained the dendrogram (Annex 1), which shows the hierarchical relationships between clusters. The height of each branch on the dendrogram represents the level of similarity or difference that exists between these clusters. To calculate the distance between two clusters in a dendrogram, we used the mean link method, which is the average of the distances between each observation or variable in one cluster and each observation or variable in the other cluster. Usually, the formula for the mean link method for the distance from cluster 1 to cluster 2 (d12) is:

$$d12 = \frac{1}{ab} \sum_{i=1}^{a} \sum_{j=1}^{b} d\,(Xi, Yj)$$

where X_1, X_2, ... X_k = observations from group 1; Y_1, Y_2, ... Y_k = observations from group 2; a = number of clusters; b = number of cases; $d_{(X,Y)}$ = distance between a subject with observation vector X and a subject with observation vector Y.

Based on the data selected in the cluster analysis, we also analyzed the Spearman correlation indicator between the variables to identify which are the strongest statistically significant correlations. The correlation coefficient of Spearman ranks can be applied to any type of variable and does not require the assumption of a normal bivariate distribution of the chosen variables of interest. The sign of the Spearman correlation coefficient indicates the direction of association (inversely proportional for the sign - and directly proportional for the + sign) between the investigated variables. The values are between +1 and -1. If the obtained values of the Spearman coefficient is closer to 0 the correlation is weak or very weak, if the coefficient is between ±0,4 and ±0,6 the correlation strength is moderate, while if they are above ±0,6 or ±0,8, the correlations are strong or very strong. The formula used is as follows:

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}$$

ρ = Spearman's rank correlation coefficient
d_i = difference between the two ranks of each observation
n = number of observations

Panel data model

The analysis uses a fixed-effects econometric panel data model to test several perspectives on the effects of energy transition policies during the last decade (2010-2021) among EU member countries. The software program utilised was Eviews 8. The aim was to spot the current status quo within European states and, at the same time, to identify the influence from various essential aspects of the sub-models, such as the level of investment (INVEST), GDP per capita (GDPCAP), the share of renewable energy sources (REW), or the share of industry (IND) in the overall economy. We synthetically explained the theoretical expected influence in *Table 2*.

Panel data models combine the *temporal* dimension (t) with the *cross-sectional* dimension (**i**), thus obtaining a two-dimensional data set. An important advantage of using *panel* data models, compared to models that use only time series or only cross-sectional data, is that they allow the identification of parameters without considering some restrictive assumptions. The basic form of this model for a cross-sectional unit ***i*** is as follows:

$$\mathbf{Y}_{it} = \mathbf{c}_i + \beta * \mathbf{X}_{it} + \mathbf{u}_{it},$$

with $t = 1,2,...,t$ and where Xit is the explanatory variable, u_{it} is the residual error with mean 0 and c_i is the constant (or control variable).

Panel data models with *random effects are usually used*, for cases where unobserved characteristics (ci) are not correlated with explanatory variables (X_{it}) - if Cor (x_{it}, c_i) equals 0. However, if *Cor* (X_{it}, c_i) is different from 0, then either a fixed-effects estimate or an estimate made using the first difference should be used.

Table 2. Theoretical influence of the selected explanatory variables

Variable	Theoretical influence
Investment (INVEST)	The relationship between investment and environmental emissions is framed within the EKC hypothesis, which posits that environmental degradation first increases and then decreases with country income (Stern, 2004). Investment, especially in industrial activities, is often associated with higher emissions due to the increased production and energy consumption required (Grossman and Krueger, 1995). However, investment in cleaner technologies and green infrastructure could reverse this trend, leading to a decoupling of economic growth from environmental harm (Jaffe et al., 2002). The significance and direction of this relationship can vary depending on the type of investment and the stage of economic development a country is in (Dinda, 2004).
GDP per capita (GDPCAP)	The GDP per capita variable is typically linked to emissions through the scale effect, where higher income leads to greater consumption and production, thus increasing emissions (Shafik and Bandyopadhyay, 1992). As economies grow, their energy needs usually increase, resulting in higher carbon emissions unless there is a simultaneous shift towards more efficient technologies and renewable energy sources (York and McGee, 2017). This link is also grounded in the EKC hypothesis, which suggests that after a certain income threshold, the relationship may invert, with further increases in GDP leading to investments in cleaner technology and lower emissions (Dinda, 2004).
Industry (IND)	The industrial sector is traditionally associated with high levels of emissions due to its reliance on fossil fuels for energy-intensive processes (Schandl et al., 2016). The structural shift from agriculture to industry usually leads to a rise in emissions, a pattern observed in the early stages of many countries' development (Hettige et al., 1992). However, within the industry variable, there are different trajectories, as some industries may adopt cleaner technologies and more efficient resource use, mitigating their environmental impact.
Renewable Energy (RENEW)	The adoption of renewable energy represents a crucial factor in reducing emissions, replacing fossil fuels with cleaner sources that have a lower carbon footprint (Jacobson & Delucchi, 2011). The inverse relationship between renewable energy consumption and emissions highlights the displacement effect, where renewables offset the demand for traditional energy sources, leading to a reduction in overall emissions (Menyah & Wolde-Rufael, 2010). The transition to renewable energy is an essential component of sustainable development strategies aimed at decoupling economic growth from environmental degradation (Goldemberg, 2007).

Source: Authors' work based on literature review.

Results and discussions

Cluster analysis results

The selected variables and software processing of data based on the hierarchical cluster analysis resulted in three main country groups, while three states, respectively Estonia, Ireland, and Luxembourg, form an individual cluster based on their particularities compared to first category.

Table 3 summarizes the identified clusters, the firs one formed by the Nordic countries (Sweden, Denmark, and Finland) with Germany, the Netherlands, Austria, and Belgium, which are consolidated and have similar characteristics. A second cluster of states targets post-communist countries (Bulgaria, Romania, Poland, Hungary, Latvia, Slovakia) alongside Croatia, but also countries in Southern Europe, such as Portugal and Greece. The third cluster includes Italy, Spain, Cyprus, Malta, along with France, Slovenia and Czechia.

Table 3. Clusters of countries

Clusters					
1	**2**	**3**	**4**	**5**	**6**
Belgium	Bulgaria	Czechia	Estonia	Ireland	Luxembourg
Denmark	Greece	Spain			
Germany	Croatia	France			
Netherlands	Latvia	Italy			
Austria	Hungary	Cyprus			
Finland	Polonia	Malta			
Sweden	Portugal	Slovenia			
	Romania				
	Slovakia				

Source: author's presentation based on Eurostat and World Bank data.

Clusters characterized by higher shares of renewable energy and lower per capita emissions (e.g., the Nordic countries, Germany, the Netherlands, Austria, and Belgium) demonstrates also stronger economic performance in terms of GDP per capita, compared to clusters with lower shares of renewable energy and higher per capita emissions (e.g., post-communist countries and Southern Europe), according to Table 4.

Table 4. Common characteristics within the clusters

Cluster	Common characteristics
Cluster 1	● GDP per capita ● Share of energy from renewable resources ● Income inequalities
Cluster 2	● Share of industry in GDP ● Quality of governance
Cluster 3	● Resources productivity ● Emissions per capita ● Circularity rate

Source: author's presentation based on Eurostat and World Bank data.

The correlation matrix (based on the Spearman correlation coefficient) presented in Table 5 shows the relationships between the selected indicators at the level of EU member states (correlations are considered statistically significant at the 0.01 and 0.05 levels). Thus, we obtain a statistically significant strong correlation (larger than +/- 0.8) between the level of government quality (GOVQ) and GDP per capita at PPP (GDP), between social protection expenditures (SOCPROT) and the share of government expenditures in GDP (PUB_EXP), but also between the level of the poverty rate (POV) and the level of the Gini index of income inequality (GINI).

There is also a high level of correlation, with coefficient values over 0.7, between the share of energy in GDP (ENERG) and the GDP per capita indicator at PPP (GDP) but also the rate of revenues from environmental taxes in total revenues government (ENV_TAX). A statistically significant correlation was also found between these last two variables.

These variables, as well as the full matrix of positive or negative correlations, are presented in Table 5, highlighting the correlations in which the Spearman coefficient is statistically significant and with high or moderate values, i.e. above +/- 0.4. In this case, we can also mention the direct correlation that resource productivity (RESPROD) has with the level of GDP per capita at PPP, but also with the share of energy in GDP, where there is a negative correlation.

Table 5. Spearman correlation matrix

Correlations

			ResProd	EMIS	CIRC	InvestCirc	RENEW	FOSS	ENERG	EN_DEP	POV	UNEM	GINI	SOCPROT	ARREARS	GDP	INVEST	INDUSTRY	ENVTAX	PUB_EXP	GOVQ
Spearman's rho	ResProd	Correlation Coefficient	1.000	0.004	.554**	0.330	-.536**	-0.166	-.602**	.478*	-0.220	-0.226	-0.301	.490**	-.457*	.613**	-0.125	-0.331	-0.357	0.259	0.295
		Sig. (2-tailed)		0.983	0.003	0.093	0.004	0.407	0.001	0.012	0.270	0.256	0.127	0.009	0.016	0.001	0.535	0.092	0.068	0.192	0.136
	EMIS	Correlation Coefficient	0.004	1.000	0.241	-0.012	-0.295	0.210	-0.295	-0.028	-0.290	-0.333	-0.210	0.112	-0.294	.446*	-0.007	0.074	-0.090	-0.103	.442*
		Sig. (2-tailed)	0.983		0.226	0.951	0.135	0.292	0.144	0.889	0.143	0.089	0.293	0.579	0.137	0.020	0.973	0.715	0.654	0.609	0.021
	CIRC	Correlation Coefficient	.554**	0.241	1.000	.445*	-0.218	-0.063	-0.295	-0.117	-.405*	-.449*	-.409*	.652**	-.596**	.492**	0.060	-0.199	-0.145	.453*	.417*
		Sig. (2-tailed)	0.003	0.226		0.020	0.275	0.756	0.143	0.561	0.036	0.019	0.034	0.000	0.001	0.009	0.765	0.319	0.470	0.018	0.030
	InvestCirc	Correlation Coefficient	0.330	-0.012	.445*	1.000	-0.149	-0.291	-.413*	0.111	-0.030	-.418*	-0.018	0.178	-.480*	0.271	0.009	-0.373	-0.283	0.089	0.271
		Sig. (2-tailed)	0.093	0.951	0.020		0.457	0.140	0.036	0.582	0.884	0.030	0.930	0.375	0.011	0.172	0.963	0.056	0.153	0.659	0.171
	RENEW	Correlation Coefficient	-.536**	-0.295	-0.218	-0.149	1.000	0.008	0.334	-.490**	0.101	0.287	0.204	-0.011	0.129	-0.225	0.200	0.147	0.021	0.261	0.052
		Sig. (2-tailed)	0.004	0.135	0.275	0.457		0.970	0.096	0.010	0.617	0.147	0.307	0.957	0.521	0.260	0.317	0.466	0.915	0.188	0.798
	FOSS	Correlation Coefficient	-0.166	0.210	-0.063	-0.291	0.008	1.000	.403*	-.392*	-0.217	-0.174	-0.208	0.238	-0.004	-0.226	-0.044	.571**	.404*	0.135	-0.214
		Sig. (2-tailed)	0.407	0.292	0.756	0.140	0.970		0.041	0.043	0.276	0.385	0.298	0.232	0.984	0.257	0.829	0.002	0.036	0.502	0.284
	ENERG	Correlation Coefficient	-.602**	-0.295	-0.295	-.413*	0.334	.403*	1.000	-.528**	0.236	0.205	0.195	-0.344	0.304	-.758**	0.131	.431*	.744**	-0.261	-.604**
		Sig. (2-tailed)	0.001	0.144	0.143	0.036	0.096	0.041		0.006	0.245	0.314	0.339	0.085	0.131	0.000	0.524	0.028	0.000	0.198	0.001
	EN_DEP	Correlation Coefficient	.478*	-0.028	-0.117	0.111	-.490**	-.392*	-.528**	1.000	0.175	0.206	0.141	0.093	0.048	0.243	-.447*	-0.365	-.414*	-0.089	-0.011
		Sig. (2-tailed)	0.012	0.889	0.561	0.582	0.010	0.043	0.006		0.382	0.302	0.482	0.646	0.812	0.222	0.019	0.062	0.032	0.658	0.958
	POV	Correlation Coefficient	-0.220	-0.290	-.405*	-0.030	0.101	-0.217	0.236	0.175	1.000	.513**	.886**	-0.339	.594**	-.511**	-0.194	-0.127	0.303	-0.363	-.598**
		Sig. (2-tailed)	0.270	0.143	0.036	0.884	0.617	0.276	0.245	0.382		0.006	0.000	0.084	0.001	0.006	0.333	0.529	0.124	0.063	0.001
	UNEM	Correlation Coefficient	-0.226	-0.333	-.449*	-.418*	0.287	-0.174	0.205	0.206	.513**	1.000	.528**	-0.055	.633**	-.469*	-0.350	-0.184	0.244	-0.004	-.419*
		Sig. (2-tailed)	0.256	0.089	0.019	0.030	0.147	0.385	0.314	0.302	0.006		0.005	0.786	0.000	0.014	0.073	0.357	0.220	0.984	0.030
	GINI	Correlation Coefficient	-0.301	-0.210	-.409*	-0.018	0.204	-0.208	0.195	0.141	.886**	.528**	1.000	-0.327	.525**	-.463*	-0.345	-0.183	0.191	-.429*	-.487*
		Sig. (2-tailed)	0.127	0.293	0.034	0.930	0.307	0.298	0.339	0.482	0.000	0.005		0.096	0.005	0.015	0.078	0.361	0.341	0.026	0.010
	SOCPROT	Correlation Coefficient	.490**	0.112	.652**	0.178	-0.011	0.238	-0.344	0.093	-0.339	-0.055	-0.327	1.000	-.434*	.417*	-0.182	-0.226	-0.219	.804**	0.372
		Sig. (2-tailed)	0.009	0.579	0.000	0.375	0.957	0.232	0.085	0.646	0.084	0.786	0.096		0.024	0.030	0.362	0.257	0.272	0.000	0.056
	ARREARS	Correlation Coefficient	-.457*	-0.294	-.596**	-.480*	0.129	-0.004	0.304	0.048	.594**	.633**	.525**	-.434*	1.000	-.683**	-0.237	0.078	.432*	-0.214	-.671**
		Sig. (2-tailed)	0.016	0.137	0.001	0.011	0.521	0.984	0.131	0.812	0.001	0.000	0.005	0.024		0.000	0.233	0.699	0.024	0.284	0.000
	GDP	Correlation Coefficient	.613**	.446*	.492**	0.271	-0.225	-0.226	-.758**	0.243	-.511**	-.469*	-.463*	.417*	-.683**	1.000	0.170	-0.253	-.729**	0.289	.867**
		Sig. (2-tailed)	0.001	0.020	0.009	0.172	0.260	0.257	0.000	0.222	0.006	0.014	0.015	0.030	0.000		0.396	0.203	0.000	0.144	0.000
	INVEST	Correlation Coefficient	-0.125	-0.007	0.060	0.009	0.200	-0.044	0.131	-.447*	-0.194	-0.350	-0.345	-0.182	-0.237	0.170	1.000	.469*	-0.068	-0.060	0.247
		Sig. (2-tailed)	0.535	0.973	0.765	0.963	0.317	0.829	0.524	0.019	0.333	0.073	0.078	0.362	0.233	0.396		0.014	0.738	0.767	0.214
	INDUSTRY	Correlation Coefficient	-0.331	0.074	-0.199	-0.373	0.147	.571**	.431*	-0.365	-0.127	-0.184	-0.183	-0.226	0.078	-0.253	.469*	1.000	0.249	-0.255	-0.245
		Sig. (2-tailed)	0.092	0.715	0.319	0.056	0.466	0.002	0.028	0.062	0.529	0.357	0.361	0.257	0.699	0.203	0.014		0.210	0.199	0.218
	ENVTAX	Correlation Coefficient	-0.357	-0.090	-0.145	-0.283	0.021	.404*	.744**	-.414*	0.303	0.244	0.191	-0.219	.432*	-.729**	-0.068	0.249	1.000	-0.243	-.590**
		Sig. (2-tailed)	0.068	0.654	0.470	0.153	0.915	0.036	0.000	0.032	0.124	0.220	0.341	0.272	0.024	0.000	0.738	0.210		0.221	0.001
	PUB_EXP	Correlation Coefficient	0.259	-0.103	.453*	0.089	0.261	0.135	-0.261	-0.089	-0.363	-0.004	-.429*	.804**	-0.214	0.289	-0.060	-0.255	-0.243	1.000	0.330
		Sig. (2-tailed)	0.192	0.609	0.018	0.659	0.188	0.502	0.198	0.658	0.063	0.984	0.026	0.000	0.284	0.144	0.767	0.199	0.221		0.093
	GOVQ	Correlation Coefficient	0.295	.442*	.417*	0.271	0.052	-0.214	-.604**	-0.011	-.598**	-.419*	-.487*	0.372	-.671**	.867**	0.247	-0.245	-.590**	0.330	1.000
		Sig. (2-tailed)	0.136	0.021	0.030	0.171	0.798	0.284	0.001	0.958	0.001	0.030	0.010	0.056	0.000	0.000	0.214	0.218	0.001	0.093	
		N	27	27	27	27	27	27	26	27	27	27	27	27	27	27	27	27	27	27	27

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Source: author's research based on Eurostat and World Bank data prelucrated in SPSS 26.

Panel data output

The model analyzed the impacts of investment, GDP per capita, industry, and renewable energy usage on the percentage change in emissions. The results suggest that GDP per capita is positively associated with emissions changes, while renewable energy is negatively associated. The variable for investment (with a lag of one period) is statistically significant at a 15% threshold, and the industry variable's significance is for 10% threshold (see Annex 2).

Estimation Equation:
=========================
D(LOG(EMIS)) = C(1) + C(2)*D(LOG(INVEST(-1))) + C(3)*D(LOG(GDPCAP)) + C(4)*D(LOG(INDUSTRY(-1))) + C(5)*D(LOG(RENEW)) + [CX=F]

Substituted Coefficients:
=========================
D(LOG(EMIS)) = -0.0296 - 0.0639*D(LOG(INVEST (-1))) + 0.58*D(LOG(GDPCAP)) + 0.144*D(LOG(INDUSTRY(-1))) - 0.128*D(LOG(RENEW)) + [CX=F]

The dependent variable being predicted is the logarithmic difference of Emissions (D(LOG(EMIS))), reflecting the percentage change in emissions over time. The data timeframe (after adjustment) is 2012 – 2021, using 270 observations, which indicates a balanced panel (every cross-section includes data for every period).

The results obtained in the model for the adjusted period 2010-2021 show a negative relationship between emissions and investments, even if the coefficient is very low (0.06). Important to note is the correlation between GDP per capita and emissions, which in this model was over 0.58, showing that an increase in GDP per capita by one percent during the analyzed timeframe led to an increase in emissions by more than half a percent.

Although with a lower impact, the change in the share of industry in GDP has a positive relationship with the level of emissions per capita. An increase in the share of industry by 1 p.p. led to an increase in emissions per capita of 0.14 p.p.

As one would reasonably expect, the model presents the favourable impact of increasing the share of renewable resources in the energy mix, respectively an increase in the share of renewable resources in the production mix during 2010-2021 led to a decrease in emissions by 0.13 p.p.

The explanatory capacity of the variables selected in the model is about 29%, respectively the four selected independent variables explain about 29% of the behavior of the dependent variable, suggesting that other factors impact emissions but are not taken into account in this model.

Conclusion

This study has systematically explored the particularities of the European Union, employing a hierarchical cluster methodology and panel data analysis to understand the broader implications for the EU's economic restructuring amid the energy transition.

Our findings reveal that investments in renewable energy sources and sustainable practices have significantly contributed to reducing per capita emissions across EU Member States, thereby altering the economic model towards a more sustainable and resilient framework. The positive association between the GDP per capita and emissions highlights the complex interplay between economic growth and energy transition and environmental sustainability, while the inverse relationship between renewable energy usage and emissions underscores the pivotal role of sustainable energy in achieving the EU's decarbonization goals.

Our panel data model shows that both overall investments in GDP and increased share of renewable energy have led to lower per capita emissions across EU Member States, contributing to the development of a new or re-shaped economic model, especially investments in the use of renewable energy resources.

The cluster analysis revealed distinct groups of EU Member States, each following a unique pathway in the energy transition process. This diversity underscores the importance of context-specific strategies over a one-size-fits-all approach, highlighting the need for policies that are tailored to the unique energy profiles, economic structures, and social conditions of each cluster. Clusters with higher levels of renewable energy adoption tend to show more favorable economic indicators, such as higher GDP per capita and lower unemployment rates. This suggests a positive correlation between sustainable energy practices and economic prosperity, reinforcing the argument for renewable energy investments as a catalyst for economic growth and stability.

The analysis indicates that clusters leading in emission reductions and energy efficiency also demonstrate strong commitments to innovation and technology adoption in the energy sector. This emphasizes the role of technological advancements and efficiency improvements in driving down emissions, pointing to the need for continuous investment in research and development to support the transition towards a low-carbon economy.

Moreover, the cluster analysis highlights significant socio-economic disparities among the EU Member States in terms of their energy transition progress, but also in terms of quality of governance and resource productivity. This disparity calls for a more equitable approach to the energy transition, ensuring that all Member States have access to the resources and support needed to overcome barriers and achieve their energy and climate goals.

Both research hypotheses were validated by our methodologies. There is an energy transition significantly associated with differences in economic performance among EU Member States, while the panel data results show that increased investment in renewable energy sources reduces per capita emissions in EU Member States.

Even though the results are robust, and the research hypotheses were validated, there are some limitations in our work. Firstly, the fixed-effects models control for unobserved heterogeneity across entities but may overlook the potential endogeneity between investment in renewable energy and economic performance, potentially biasing the results. Secondly, our study identifies distinct clusters of EU Member States - with unique pathways in the energy transition process - but the socio-economic, political, and environmental contexts of these countries vary significantly, and more deeper understanding of specific national or regional contexts within the EU, with additional variables is required, as unique factors may influence the energy transition process. The focus on aggregate indicators such as GDP per capita, investment in GDP, and share of renewable resources might overlook critical factors such as technological advancements and energy policy specific frameworks that could significantly influence the energy transition and economic restructuring outcomes. Finally, the study acknowledges that the four selected variables (GDP per capita, investment, industry and renewable energy sources) explain about 29% of the behavior of the dependent variable (CO2 emissions per capita), suggesting that other impactful factors were not included in the model.

In this context, while the research paper provides valuable insights into the EU's energy transition and its implications for economic restructuring, the limitations outlined above suggest areas for further refinement and exploration. Thus, future research should explore the potential of emerging technologies and innovative financing models to accelerate the energy transition until 2040-2050. Moreover, the study highlights the socio-economic implications of the energy transition, including the potential for job creation in new industries and the risk of exacerbating inequalities. Further research should dive into strategies for ensuring a just transition that benefits all sectors of society, particularly vulnerable communities and transition regions.

Other discussions could explore which sectors stand to gain or lose the most from shifts towards renewable energy and how these changes might influence overall economic resilience and sustainability, offering a more comprehensive understanding of the challenges and opportunities ahead. The energy transition's impact on regional energy security within the EU offers another rich area for discussion. This could include analyzing how dependency on renewable energy sources varies across regions and the implications for energy supply stability, especially in light of geopolitical tensions and supply chain disruptions.

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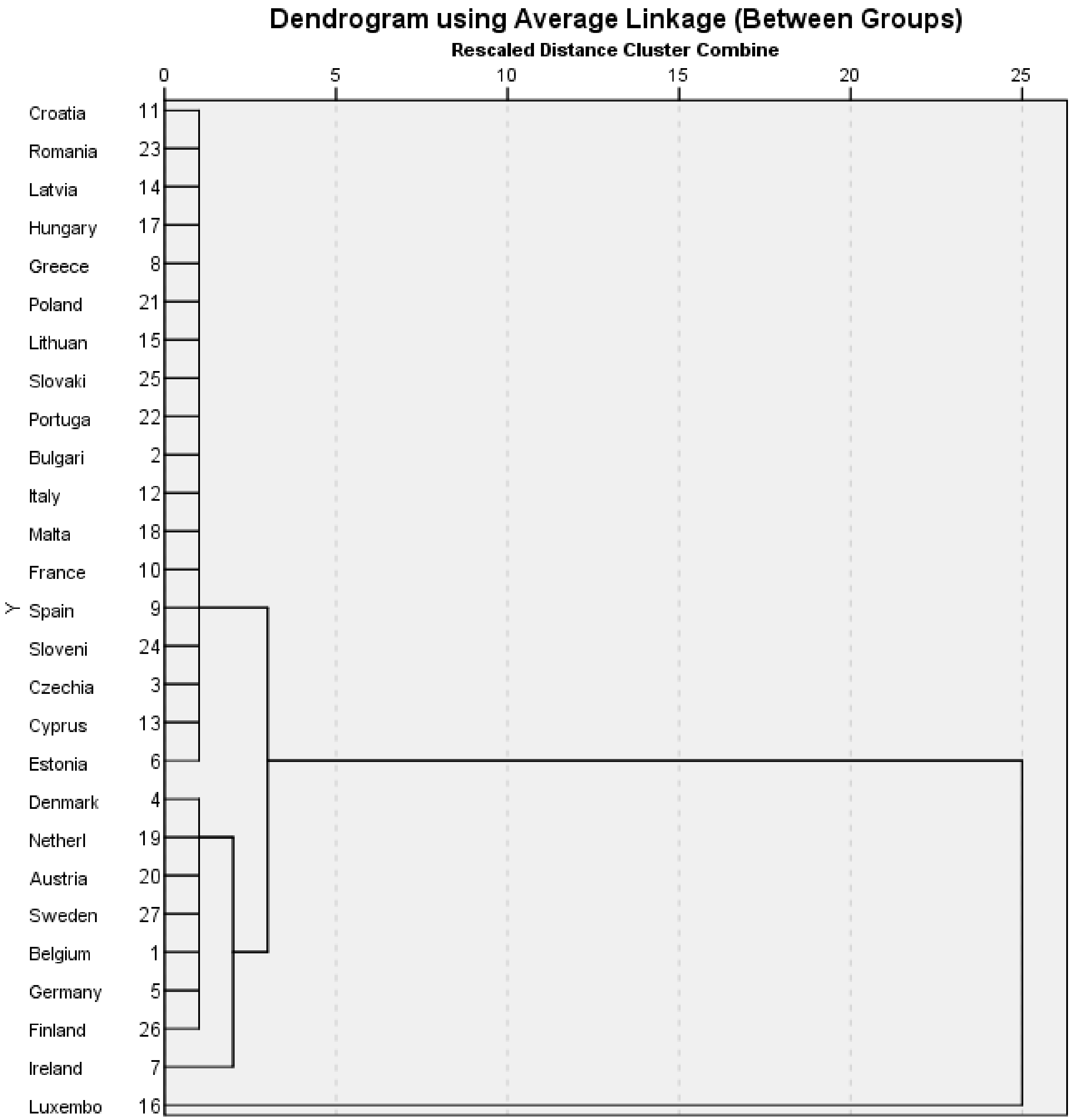
ANNEX 1



Source: author's research based on Eurostat and World Bank data prelucrated in SPSS 26.

ANNEX 2

Dependent Variable: D(LOG(EMIS))
Method: Panel Least Squares
Date: 08/04/23 Time: 15:13
Sample (adjusted): 2012 2021
Periods included: 10
Cross-sections included: 27
Total panel (balanced) observations: 270

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.029604	0.005426	-5.455418	0.0000
D(LOG(INVEST(-1)))	-0.063948	0.042453	-1.506317	0.1333
D(LOG(GDPCAP))	0.581770	0.094120	6.181131	0.0000
D(LOG(INDUSTRY(-1)))	0.144229	0.076817	1.877575	0.0617
D(LOG(RENEW))	-0.128079	0.045811	-2.795793	0.0056

Effects Specification

Cross-section fixed (dummy variables)

BELGIUM	0.009300
BULGARIA	-0.006963
CZECHIA	-0.001227
DENMARK	-0.018141
GERMANY	-0.002653
ESTONIA	-0.038999
IRELAND	-0.012241
GREECE	0.001932
SPAIN	0.000823
FRANCE	0.005197
CROATIA	-0.001889
ITALY	0.001738
CYPRUS	0.017346
LATVIA	0.007191
LITHUANIA	0.031849
LUXEMBOURG	0.024486
HUNGARY	0.006249
MALTA	-0.025772
NETHERLANDS	0.011379
AUSTRIA	0.006787
POLAND	0.011018
PORTUGAL	0.002825
ROMANIA	-0.006730
SLOVENIA	-0.006506
SLOVAKIA	0.011147
FINLAND	-0.016383
SWEDEN	-0.011763

R-squared	0.287128	Mean dependent var	-0.019714
Adjusted R-squared	0.197646	S.D. dependent var	0.063423
S.E. of regression	0.056810	Akaike info criterion	-2.790521
Sum squared resid	0.771356	Schwarz criterion	-2.377369
Log likelihood	407.7203	Hannan-Quinn criter.	-2.624617
F-statistic	3.208787	Durbin-Watson stat	2.023060
Prob(F-statistic)	0.000000		

Source: author's research based on Eurostat and World Bank data prelucrated in Eviews 8.